# [EN-040] Results from an Interval Management (IM) Flight Test and Its Potential Benefit to Air Traffic Management Operations

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**Abstract:** NASA's first Air Traffic Management Technology Demonstration (ATD-1) subproject successfully completed a 19-day flight test of an Interval Management (IM) avionics prototype. The prototype was built based on IM standards, integrated into two test aircraft, and then flown in real-world conditions to determine if the goals of improving aircraft efficiency and airport throughput during high-density arrival operations could be met.

The ATD-1 concept of operation integrates advanced arrival scheduling, controller decision support tools, and the IM avionics to enable multiple time-based arrival streams into a high-density terminal airspace. IM contributes by calculating airspeeds that enable an aircraft to achieve a spacing interval behind the preceding aircraft. The IM avionics uses its data (route of flight, position, etc.) and Automatic Dependent Surveillance–Broadcast (ADS-B) state data from the Target aircraft to calculate this airspeed.

The flight test demonstrated that the IM avionics prototype met the spacing accuracy design goal for three of the four IM operation types tested. The primary issue requiring attention for future IM work is the high rate of IM speed commands and speed reversals. In total, during this flight test, the IM avionics prototype showed significant promise in contributing to the goals of improving aircraft efficiency and airport throughput.

**Key Words**: Interval Management, air traffic management, avionics, flight test, cockpit procedures.

## 1 Introduction

The National Aeronautics and Space Administration's (NASA) Air Traffic Management Technology Demonstration (ATD-1) sub-project conducted a 19-day flight test in 2017. In this test, three aircraft were used to explore the feasibility and benefit of Interval Management (IM) operations by flying multiple en route, arrival, and final approach scenarios (ref. 1). This paper describes the operational need, the concept of operations to address this need, development of the IM avionics prototype, preparation for the flight test, results of the flight test, and conclusions for moving closer to operational implementation of the IM concept.

### 1.1 Background

The Federal Aviation Administration's (FAA) 2015-2035 Aerospace Forecast predicted U.S. commercial aviation revenue passenger miles would grow on average 1.8% annually over twenty years (ref. 2). By 2035, U.S. commercial air carriers were projected to fly 1.71 trillion available seat-miles – approximately 167% of the seat-miles flown in 2014. Arrivals into high-density airports frequently experience inefficient arrival operations due to the use of miles-in-trail procedures and step-down descents, especially during peak traffic flow or inclement weather. Current arrival procedures can result in higher than necessary aircraft fuel burn, emissions, controller workload, and delay, and may fail to achieve the airport's maximum arrival capacity.

In addition to NASA's ATD-1 sub-project, interested stakeholders from government and industry collaborated to develop a Minimum Operational Performance Standards (MOPS) (ref. 3). This committee was composed of operational, regulatory, policy, and engineering specialists from various global air navigation service providers; the FAA and European Aviation Safety Agency regulators; multiple aircraft operator and professional organizations; pilot, air traffic control, and labor representatives; avionics and airframe manufacturers; and research organizations (NASA, NLR, ENRI, MITRE CAASD, and MIT Lincoln Labs). The MOPS was developed using a standard structured process based on foundational work defined by a concept of operation, operational performance assessments, and operational safety assessments; all of

which are based on consensus driven collaboration among all stakeholders.

### 1.2 ATD-1 Concept of Operations

The ATD-1 concept addresses the projected increase in flight operations by precisely delivering the aircraft to the final approach fix (FAF), thereby reducing the extra spacing buffer normally added to the required minimum separation requirement. To achieve this goal, the ATD-1 concept integrates three NASA research elements, each developed with the FAA and industry partners, to achieve high throughput and fuel-efficient arrival operations into a busy terminal airspace (ref. 4). This concept was developed during the project's five-year span, and effort was made to keep it aligned with the FAA concept for IM operations (ref. 5).

The ATD-1 concept consists of three research elements. The first research element, Traffic Management Advisor with Terminal Metering (TMA-TM), generates a time-deconflicted arrival schedule to a series of metering points, which include the runway threshold, FAF, and merge points. The second element, Controller-Managed Spacing (CMS), provides information to help terminal area air traffic controllers manage aircraft delay using speed control. The third element, IM, provides the speed guidance necessary to allow flight crews to manage their spacing behind an assigned lead aircraft. Throughout this paper, the IM equipped aircraft is referred to as the Ownship and the lead aircraft is referred to as the Target.

When an aircraft crosses the Freeze Horizon, the schedule calculated by TMA-TM is frozen, setting specific times for that aircraft to arrive at the meter points, thereby ensuring adequate spacing from other aircraft. The en route or terminal controller meter lists, and the CMS and IM information shown on the controller displays, are calculated from the TMA-TM schedule information.

En route controllers issue the arrival procedure and expected runway to all aircraft. When speed control is sufficient to achieve the schedule and the desired spacing intervals, the en route controller issues an IM clearance to the flight crew of the Ownship aircraft. The clearance includes the Target's flight identification (or "callsign"), the Target's route of flight, the Assigned Spacing Goal (ASG), the point at which the IM operation is complete (the Planned Termination Point, PTP), and, if appropriate, the point at which the spacing interval must be achieved (the Achieve By Point, ABP). The flight crew enters their route of flight and IM clearance information into the IM avionics and then flies the calculated speeds to achieve or maintain the desired spacing interval behind the Target. Terminal controllers use the CMS decision support tools to help aircraft that are not conducting IM operations meet the schedule calculated by TMA-TM.

### 1.3 IM Operations Conducted in Flight Test

The four IM operation types conducted during the flight test were Maintain, Capture, Cross (divided into two subtypes), and Final Approach Spacing.

- The Maintain clearance is used when the Ownship and Target aircraft are on a common path and the controller wants the Ownship to maintain the current in-trail spacing. The algorithm determines speeds that will continuously maintain the in-trail spacing until the operation terminates. Within this flight test, the Maintain clearance was used during en route and arrival operations.

- The Capture clearance is used when the Ownship and Target aircraft are on a common path and the controller wants the Ownship to achieve a specific ASG and then maintain it until termination. The algorithm determines speeds that will correct the initial spacing error, and then maintain the in-trail spacing until the operation terminates. This clearance is intended for use when the spacing between Ownship and the Target is close to the spacing interval required by either the controller or schedule. Within this flight test, the Capture clearance was used during en route and arrival operations.

- The Cross clearance is used when the controller wants the Ownship to achieve the ASG at the ABP, and then maintain the ASG until termination. The achieve stage is used to correct the initial spacing error by the ABP, and then transitions to the maintain stage until termination. The ASG is derived from the ground scheduling function or metering information. Within this flight test, the Cross clearance was used during arrival operations. Since the behavior of the Cross clearance is different before and after the ABP, the Cross clearance was separated into two separate experimental conditions:
    - Cross-Merge operation occurs when the ABP in the IM clearance is set as the waypoint where the Target and Ownship routes merge, and
    - Cross-FAF operation occurs when the ABP in the IM clearance is set as the FAF.

- The Final Approach Spacing clearance is used when the final controller wants to use IM to precisely achieve an ASG behind the preceding aircraft on final approach. Within this flight test, the Final Approach Spacing clearance was given to the Ownship when one aircraft was established on final, and the other aircraft was either also established on final or on a vector to intercept the final approach course.

### 1.4 Areas of Interest

The primary area of interest was the spacing accuracy of the Ownship at the ABP or PTP. Other areas of interest include the frequency of speed changes and the number of speed reversals, which are defined as the number of speed increases followed by a speed decrease or speed decreases followed by a speed increase. This paper reports on the spacing accuracy of time-based arrivals at the ABP and PTP, the rate of speed changes for IM operations compared to current day operations, and provides a case study about one of the root causes for the increased rate of speed changes when conducting IM operations.

## 2 Designing and Building the IM Avionics

This section describes the IM avionics used during the flight test, and how a future certified system would be designed and built.

### 2.1 IM Avionics Prototype Used In Flight Test

The IM avionics prototype was developed using good engineering practice but without the overhead of formal certified development processes (ref. 6). This is common practice for proof-of-concept prototypes since the effort associated with formal certified development process adds 50-100% additional labor and schedule. Since the primary aim of the flight test was to test the IM avionics prototype, the additional rigor of formal processes was not necessary and avoided significant cost and schedule impacts.

A key component of the formal certified development process is the capture, management, and control of the system requirements. The requirements for the prototype included those established by the NASA Langley Research Team and the MOPS (ref. 3). At the time that the requirements capture process began for the prototype, this MOPS was only available in draft form. As a result, some of the MOPS requirements issued after flight test planning began were excluded from the prototype system requirements. The excluded requirements had minimal impact to the operational performance of the system and the research objectives of the ATD-1 flight test for which it was designed.

While not all formal processes required for development of certified avionics were met, a comprehensive test plan was followed to ensure that the IM avionics prototype achieved the design requirements. The test plan included unit tests of individual functions and system tests using input data specified by the MOPS. Limited in-flight testing was conducted when the aircraft deployed to the airports used during flight test.

The resulting IM avionics prototype consisted of a DO-317A complaint Traffic Processing Unit, a side-mounted electronic flight bag (EFB) for each crew member, and a forward-mounted configurable graphics display (CGD) for each crew member that repeated pertinent information. The flight crew was responsible for manually entering their aircraft’s route of flight, forecast wind, and the IM clearance information required to conduct the IM operation. Once all data had been entered and the initiation criteria had been met, the flight crew procedure to fly the IM operation was to set the speed calculated by the spacing software in the mode control panel speed window, and then use the throttles and speed brakes as required to achieve and maintain that speed. This system was installed on two of the three aircraft involved in the flight test.

### 2.2 Future IM Avionics Built for Certification

Future IM systems would likely be more integrated with existing aircraft systems, such as the Flight Management Computer, datalink avionics, and auto-flight systems. In future developments of such certified IM systems, requirements should be consistent with a stable MOPS or other technical standards documents. Additionally, regulators may create certification guidance in the form of a Technical Standard Order (TSO), European TSO (ETSO), or other technical standards which certified avionics must be shown to meet. If a future IM system would be hosted in avionics hardware that has previously been certified, the hardware qualification tests would not be needed, allowing the full focus of the work to be on the software.

Upon completion of the software development, hardware and software integration, and formal system validation and verification, the developer would apply for a TSO authorization. This allows the manufacturer to mark the IM avionics with the applicable TSO and indicates that the manufacturer has shown compliance to all applicable regulations regarding the performance of the equipment as demonstrated by bench test. The final step is to seek regulatory approval to install the avionics in a Type Certificated (TC) aircraft. This may be accomplished by amending the original TC of the aircraft, which is typically only done by the aircraft manufacturer. More commonly, equipment installation regulatory authorization is accomplished by a Supplemental Type Certification (STC). This involves the installation of the avionics in accordance with an installation plan and successful completion of a formal test plan. The test plan typically involves showing that the avionics meet their intended function, do not interfere with existing aircraft equipment, the installation is safe and provides acceptable crew human factors, and the crew operational instructions are acceptable including normal and non-normal procedures.

In summary, the development of a certifiable IM system will require considerably more time and resources than was used to build and test the IM avionics prototype flown during the flight test; however, the more rigorous approach would have found and corrected many of the display ambiguities and software issues that to some degree impacted the results obtained during the flight test.

## 3 Designing and Conducting the Flight Test

This section describes how the flight test itself was designed, conducted, and the pilot procedures used to fly the IM operation.

### 3.1 Designing the Flight Test

The planning phase for the ATD-1 flight test began in the fall of 2015. One task was to identify an area where three aircraft could operate, and that would allow all three aircraft to climb to FL350 and descend via an arrival procedure to a runway threshold. After several areas were considered, the Grant County International Airport (KMWH) was identified as the ideal facility due to long runways and dedicated Terminal Radar Approach Control (TRACON) and Tower facilities which frequently conducted unique flight test operations. Furthermore, the high-altitude en route airspace surrounding KMWH was controlled by Seattle Air Route Traffic Control Center (ARTCC) which also regularly supported flight test operations in that area.

Representatives from the flight test team met with ARTCC Operational Managers to identify the areas that would allow for the most flexibility in conducting the flight test with the minimum impact on their daily operations. The facility representatives worked closely with the flight test team to assist in developing Standard Terminal Arrival Routes (STARs) connected to Required Navigation Performance Authorization Required (RNP AR) approaches into KMWH. With the support of FAA Air Traffic Organization, the FAA Flight Standards Division, and Jeppesen, STARs were approved and made available to the aircraft, pilots, and controllers participating in the flight test (Figure 1).

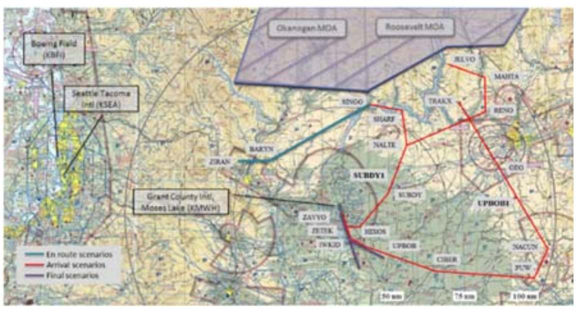


**Figure 1. ATD-1 flight test airspace and route map**

A Honeywell Dassault Falcon 900 (F-900, Figure 2, center aircraft) was used as the first aircraft in the arrival stream for each scenario. It was equipped with ADS-B Out (DO-260B compliant) and a Global Navigation Satellite System (GNSS). A Honeywell Boeing 757-200 (B-757, left aircraft) and a United Airlines Boeing 737-900 (B-737, right aircraft) were also equipped with ADS-B In/Out (DO-260B compliant) GNSS, and were equipped with the IM avionics prototype. The Honeywell aircraft were based at Boeing Field (KBFI), and the United B737 was based at the Seattle-Tacoma International Airport (KSEA).

**Figure 2. Aircraft used in ATD-1 flight test**

The flight test was designed to evaluate IM system performance during three phases of flight: en route, arrival, and final approach. Both quantitative and qualitative data were collected. During each flight test run, IM system data, aircraft state data, and FMS data were recorded on the IM equipped aircraft. The aircraft state data on the F-900 and cockpit video on the B-757 were also recorded.

### 3.2 Conducting the Flight Test

Preparations for each flight began the previous day when the test cards for the next day were sent electronically to all the participants in a format tailored to their need (air traffic controller, Flight Test Director, and pilots). The morning briefing began at 8 AM, with the Flight Test Director and all flight crew present for a face-to-face discussion, and representatives from Seattle ARTCC, Seattle TRACON, and Moses Lake TRACON dialed into the meeting. The aircraft launched from KBFI and KSEA by 09:30 AM to avoid the morning departure rush at KSEA.

Once at FL350 and approximately 20 nmi in-trail, the crews of the IM-equipped aircraft initiated the en route IM operation at ZIRAN and terminated at SINGG (Figure 1). After completing the en route scenario, the flight crew worked with the Flight Test Director to establish the start time of the next arrival scenario, coordinated with ATC to maneuver the aircraft as required to achieve the start time, and then entered the data required for the next IM operation. When the IM operation was complete, the pilots completed an end-of-scenario survey for the en route IM operation.

The flight crew flew the arrival scenarios to the PTP, which was always the FAF (ZAVYO). Upon reaching the FAF, the flight crew continued the descent to decision altitude, conducted a missed approach, and then proceeded to the initial point for the next scenario. After the arrival operations were complete, the aircraft returned to their respective airport. During the return segment, the flight crew of the B-757 and B-737 completed the final end-of-scenario survey and the end-of-day survey.

### 3.3 Flight Crew Procedures to Conduct the IM Operation

The flight crew procedures to conduct IM operations were divided into two distinct phases: 1) the programming phase when all the data required for the IM operation was entered into the prototype avionics via the EFB, and 2) the execution phase where the IM commanded speed displayed by the prototype avionics was entered into the mode control panel speed window (the vertical navigation (VNAV) speed mode).

In the programming phase, the flight crew used the side-mounted EFB (Figure 3) to enter information about the Ownship's route and destination, forecast en route and descent winds, and the IM clearance itself. The Ownship and wind information could be entered anytime, whereas the IM clearance information was entered at the beginning of each scenario.

In the execution phase, the flight crew procedure was to set the IM commanded speed from the avionics prototype into the airspeed window of the mode control panel, like entering an airspeed issued via voice instruction from the controller. While this speed was shown on the EFB (the green 260 KT in Figure 3), the CGD located in the pilot's primary forward field of view repeated the IM commanded speed and other critical information needed to execute the IM operation.


**Figure 3. IM application on Electronic Flight Bag**

## 4 Flight Test Results

The quantitative data and case study in this section is based on the 144 valid operations flown during the 19 days of flying. Additional results are available in references 7-11.

### 4.1 Maintain Stage Performance

One metric to characterize the maintain stage performance is how accurately the IM aircraft meet the ASG at the end of the maintain stage. For time-based operations, the maintain stage spacing accuracy is defined as the difference between the ASG and the spacing interval at the PTP. Negative values indicate that the spacing interval is smaller than the ASG and positive values indicate that the spacing interval is larger than the ASG. The IM benefits analysis conducted by the FAA assumes the ability for the IM aircraft to achieve a spacing interval within 10 seconds of the ASG at lead 95% of the time (ref. 12). This corresponds to a standard deviation of approximately 5 seconds if the mean spacing error is zero and the data are normally distributed.

Table 1 shows the spacing accuracy at the PTP for the time-based Maintain, Capture, and Cross-Merge arrival operations was within the 10 second goal when they crossed the PTP. For each operation, the average spacing error was within 2 seconds and the standard deviation was less than 3 seconds. This indicates the ability of those operations to attain precise spacing at the PTP.

**Table 1. Maintain stage spacing accuracy at the PTP for time-based arrival operations**

| Clearance Type | N | Mean (sec) | *SD* (sec) |
|---|---|---|---|
| Maintain | 18 | -1.13 | 2.99 |
| Capture | 32 | 0.55 | 2.63 |
| Cross-Merge | 27 | -0.47 | 2.45 |

### 4.2 Achieve Stage Performance

The achieve stage spacing accuracy measures how accurately the IM aircraft achieve the ASG at the ABP. For arrival scenarios, this metric only applies to the Cross operations. Like the maintain stage spacing accuracy, the achieve stage spacing accuracy is defined as the difference between the ASG and the spacing interval between the Ownship and Target aircraft at the ABP. The operational goal is a spacing error within 10 seconds at the ABP, 95% of the time. During the arrival scenarios, the ABP was located at either NALTE for the medium altitude merge scenarios (Cross-Merge), or at ZAVYO for the low altitude merge scenarios (Cross-FAF).

Table 2 shows the spacing performance at the ABP for the Cross-Merge and Cross-FAF operations. The average spacing accuracy of the Cross-Merge operations was -1.65 seconds with a standard deviation of 6.24 seconds. The average spacing accuracy of the Cross-FAF operations was 6.24 seconds with a standard deviation of 8.28 seconds. This performance does not meet the operational goals, though an analysis of the outliers suggests that this is largely attributable to challenges in setting up the individual scenario or errors in the IM avionics prototype software, and not the IM concept itself or the control laws being used.

Of the 25 Cross-Merge operations, four had spacing errors greater than 10 seconds. Two of these cases involved conditions at initiation that would not be expected operationally. The other two outliers for

Cross-Merge operations appeared to be normal operations with adequate speed control authority to resolve the spacing error. These two cases had spacing accuracies of 12 seconds early and 13 seconds late at the ABP.

Of the 41 Cross-FAF operations, 17 had spacing errors at the ABP greater than 10 seconds. Two primary causes were identified for the poor spacing performance. First, there was a software implementation error identified after the flight test that prevented the IM avionics prototype from consistently incorporating sensed wind information into the Ownship's and Target aircraft's trajectory predictions. This resulted in cases where the IM aircraft had significantly larger differences between the predicted headwind and actual headwind than it would have had if the software implementation error had not occurred. The second source were differences between the speeds flown by the Ownship and the speeds expected by the IM avionics during the deceleration segment prior to the FAF. These differences were caused by a combination of large procedural speed changes and functionality that provided procedural speed changes as a single speed command.

**Table 2. Achieve stage spacing accuracy at the ABP for time-based arrival operations**

| Clearance Type | N | Mean (sec) | *SD* (sec) |
|---|---|---|---|
| Cross-Merge | 25 | -1.65 | 6.24 |
| Cross-FAF | 41 | 6.24 | 8.28 |

### 4.3 IM Speed Command Rate

The IM speed command rate is the number of speed commands per minute displayed by the IM avionics to the pilots. This metric is used as an indirect measure of pilot workload since they enter that speed into the mode control panel. For current day operations without metering in effect, the rate of speed changes is driven by the number of speed constraints on the published procedure, company operating procedures, and controller instructions. Since current day arrival operations were not conducted during the ATD-1 flight test, for this analysis an approximation of these operations was made based on three speed changes during the STAR and three speed changes during the RNP AR approach. This equates to approximately 0.15 changes per minute on arrival and 0.30 changes per minute on approach.

The mean IM speed command rate for all time-based arrival operations was 0.57 speed commands per minute, or approximately one command every two minutes, which is significantly higher than current day operations. While an increase in the speed command rate is expected when comparing metered to non-metered operations, two specific characteristics of the IM speed command behavior were identified as undesirable by the flight crew: speed reversals and many speed changes within a short period of time. Several factors contributed to the undesirable speed command behaviors, including 1) differences between the forecast winds and winds experienced by the aircraft, 2) differences between the airspeeds flown by the Target aircraft and the airspeeds predicted by the IM avionics, 3) differences between the rate of deceleration expected by the control law and the Ownship's actual deceleration rate, and 4) possibly the design of the speed control law.

### 4.4 Case Study: Speed Increases prior to end of IM Operation

A behavior unique to the Cross operation when the trajectory-based speed control law was being used, and when the ABP and PTP are co-located at the end of a large procedural deceleration segment, is speed increases during the deceleration prior to the PTP. When close to the ABP, the trajectory-based control law uses proportional control. If there is a non-zero spacing error, the IM avionics will command a speed that is either slower or faster than the nominal speed to correct the spacing error. As the spacing error is corrected, the IM commanded speed will return to the nominal speed. Analysis has shown that this can result in less than ideal speed behavior during the deceleration to the PTP if there is a spacing error at the beginning of the deceleration, or if the Target aircraft is flying a speed that is slower than the nominal speed.

During an IM operation, the flight crews are shown the IM commanded speed (the '260 KT' in Figure 3), which they input into their aircraft's mode control panel speed window. IM speed commands were typically provided in 10 knot increments unless there was a speed change due to speed constraints on the arrival procedure. To reduce the number of speed commands provided to the flight crew, the IM avionics prototype provides procedural speed changes as a single speed command. A secondary speed cue, called the instantaneous speed (the 'FAST/SLOW Indicator' in Figure 3), was provided to the pilots to help follow the speeds desired by the speed control law during large procedural deceleration segments.

These two speeds are also shown in Figure 4, where the dark blue line (End Speed) in the upper panel is the IM commanded speed, and the light blue line is the instantaneous speed. The black line (Nominal CAS) in Figure 4 is the nominal speed defined by the arrival and approach procedure, the red line (CAS) is the Ownship's airspeed, and the yellow line is the control law speed. This control law speed becomes the instantaneous speed after the filtering, speed limiting, and discretization logic has been applied.

Figure 4 illustrates an example where there was a -18 second spacing error at 10.5 nmi from the PTP (the spacing interval is smaller than the ASG). When the deceleration to the FAF began, the IM commanded speed changed from 220 knots to 150 knots; the nominal 170 knots at the ABP plus -20 knots of speed control.

As the spacing error was corrected, the IM commanded speed increased to 170 knots, the nominal speed profile at the end of the deceleration segment. Both the control law speed and instantaneous speed trended toward the nominal speed profile. At the very end of the operation, IM speed increases were inhibited from increasing above the nominal speed profile to ensure that the pilots could achieve a stabilized approach.

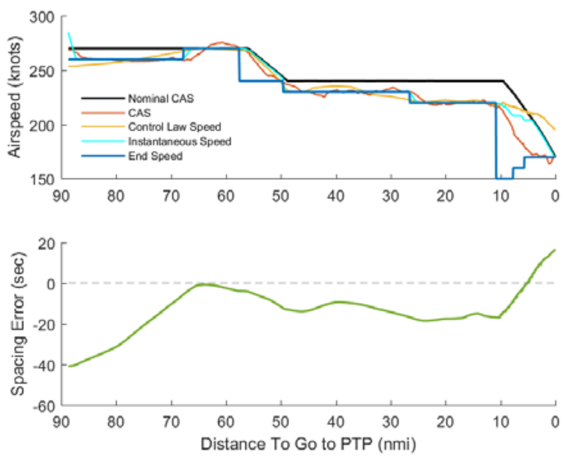


**Figure 4. Increase in IM commanded speed prior to end of operation**

The spacing error reached zero when the Ownship was approximately 5 nmi from the ABP. After the Target aircraft crossed the ABP, the Ownship's speed should have been equal to the nominal speed profile in order keep the spacing error close to zero. In this case, the IM aircraft's speed was significantly slower than the nominal speed causing the spacing error to overshoot to a value of 15.5 seconds. The instantaneous speed was depicted on the IM avionics prototype's human machine interface to mitigate this issue; however, the pilots would have had to pause their deceleration in the middle of the deceleration segment to follow it. This would have required them to increase the throttle setting to achieve the non-uniform deceleration. As a result, there were several instances where the pilots ignored the instantaneous speed and continued decelerating toward the IM commanded speed.

When it occurred, this spacing behavior was challenging for the flight crew, especially when on final configuring the aircraft for a stabilized approach. This particular spacing behavior is accentuated when the deceleration immediately prior to ABP is very large. One potential solution to explored is reducing the size of the procedural deceleration segment prior to the FAF (e.g., into 20 knot increments), or how those procedural speed changes are handled by the control law.

## 5 Conclusion

A 19-day flight test was conducted in early 2017 to measure the performance of an IM avionics prototype that was used to conduct four different types of IM operations. These IM operations are intended to precisely deliver aircraft to the PTP, thereby enabling high throughput and fuel efficient arrival operations by reducing the size of the additional spacing buffer added to the minimum separation requirement.

In general, the spacing accuracy of the IM software met or was better than the goals set by the standard. The average spacing accuracy of the IM operation at the end of the maintain phase was within 1.4 seconds and the standard deviation was less than 3.0 seconds, which is better than the operational goal. The achieve phase of the Cross-Merge operations had a mean of less than 1.7 seconds and a standard deviation of less than 6.3 seconds, which almost met the operational goal. The achieve phase of the Cross-FAF operations did not meet the operational goal due to a software implementation error, the size of the procedural speed changes, and how procedural speed changes were implemented. Some of the behavior of the IM operation, in particular the rate of speed commands generated by the IM avionics prototype, was not desirable.

The IM concept and avionics demonstrated considerable promise to improve spacing accuracy, which should support more predictable arrival rates. As these IM operations stabilize into a more repeatable experience for air traffic control and the flight crew, it is expected that the additional spacing buffer used today to accommodate the aircraft performance variation and protect separation standards may be safely reduced, thereby increasing the landing rates at airports and runways that are in high demand.

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